High Volume Manufacturing of 5G RF Transceivers

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Mesa, Arizona • May 1-4, 2022

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- Future Work
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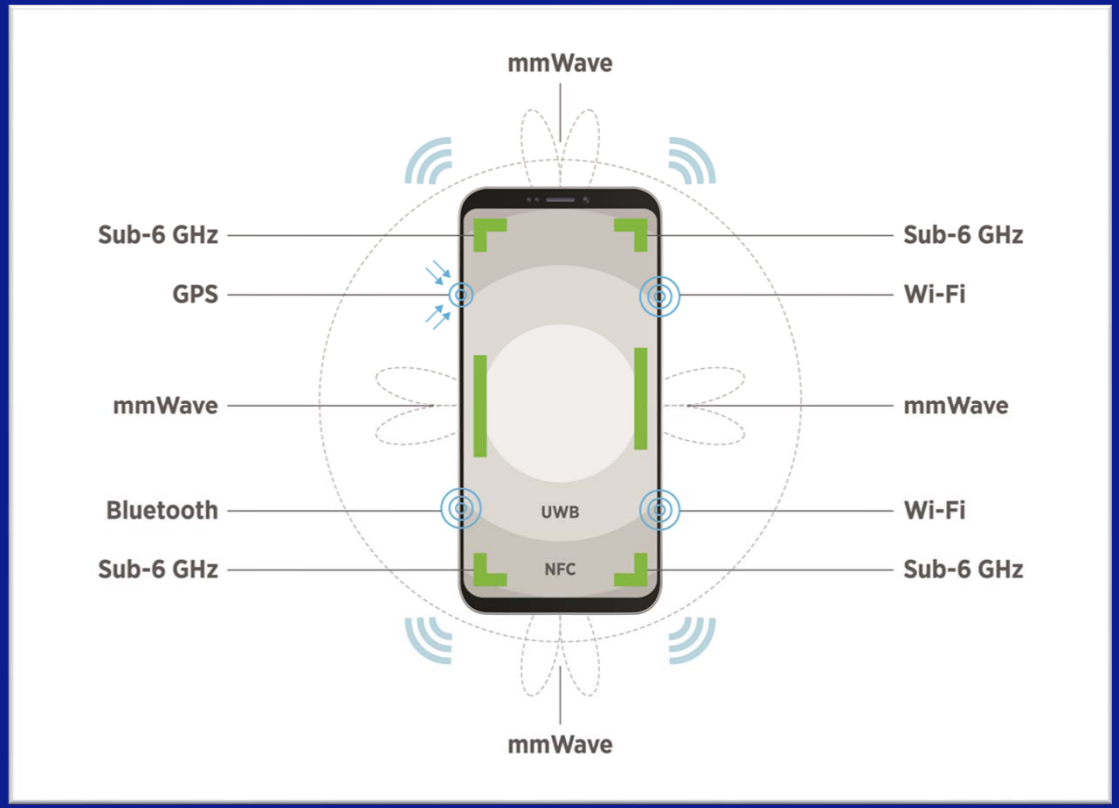
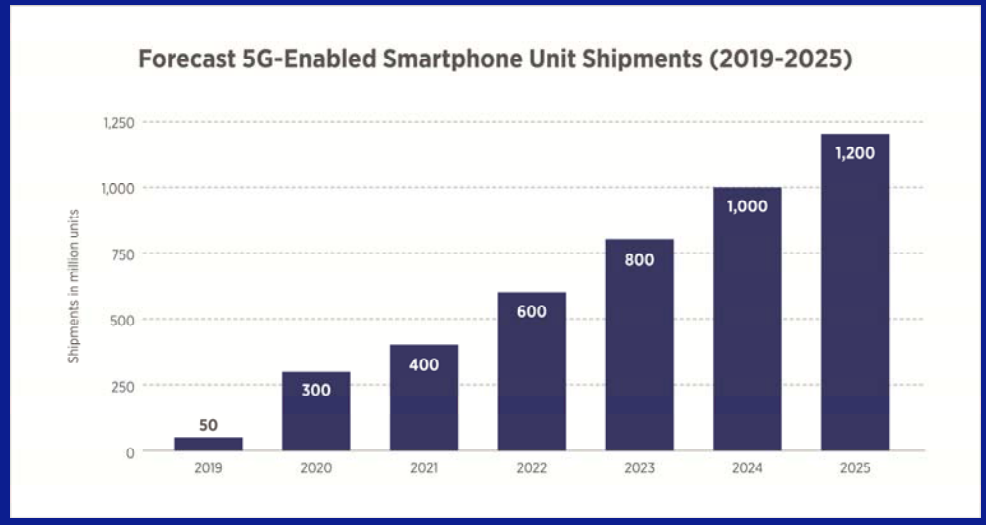


Introduction

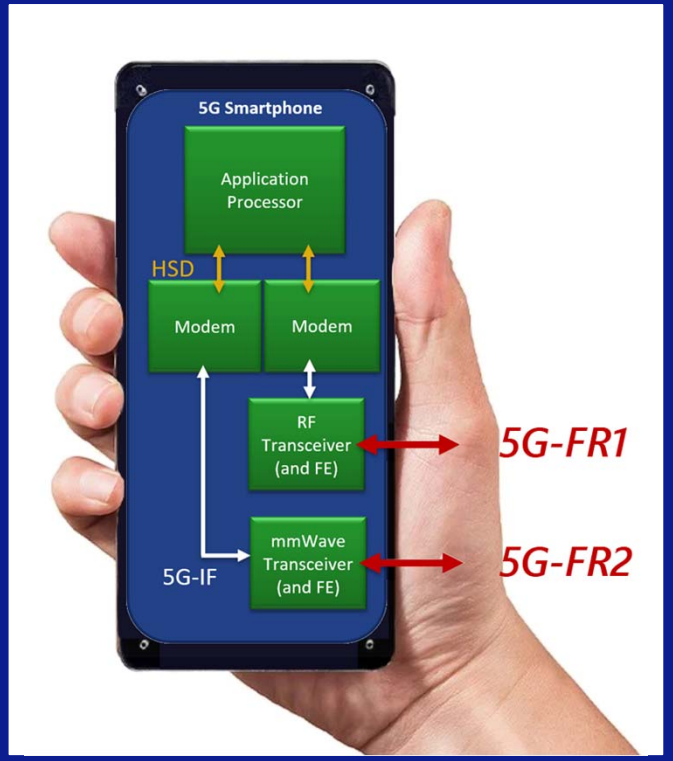
- 5G ramp imposes complexity and economic challenges throughout the semiconductor ecosystem.
- Integration complexity in 5G-FR1 (Sub-6 GHz) and 5G-FR2 (mmWave).
  - More antennas, bands, filters
  - Higher frequency, data rates
  - Greater bandwidth
- Economics in keeping smartphones affordable and profitable without sacrificing quality.



Source: Teradyne

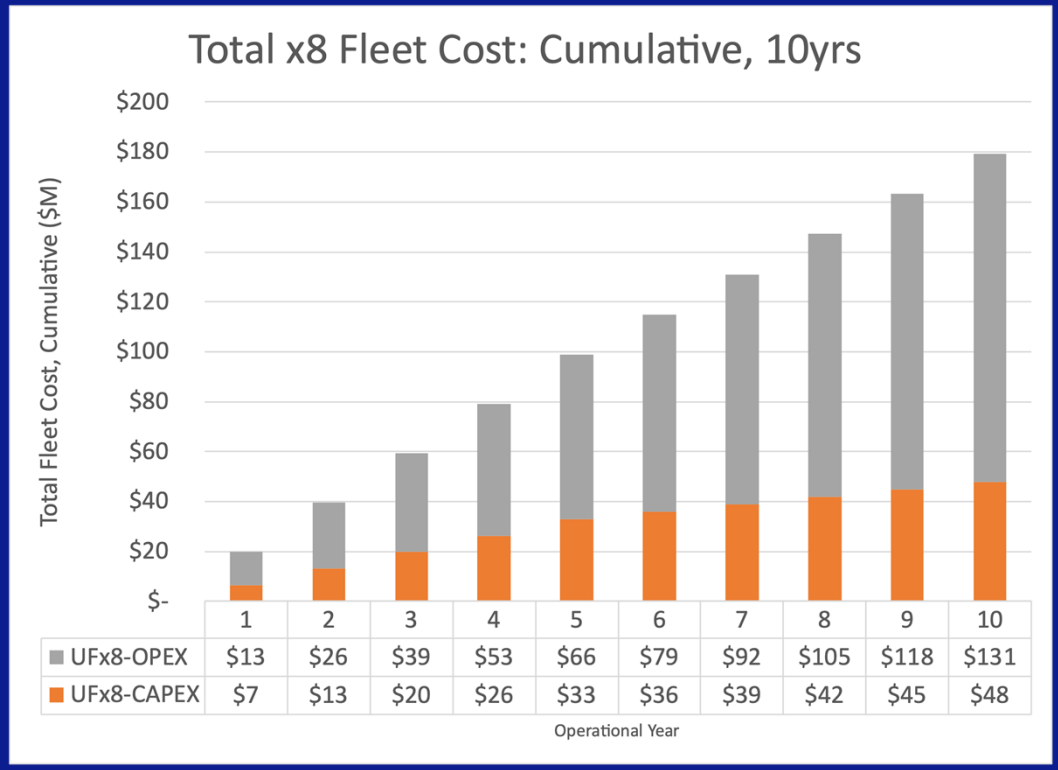
Objective

- 5G smartphone leverages automated test equipment to find manufacturing defects in RF transceivers.
- Today the baseline is x8 site density.
- Explore economic benefits of doubling the site density to x16 on total cost of test (CoT) and total cost of ownership (TCO).



Methodology

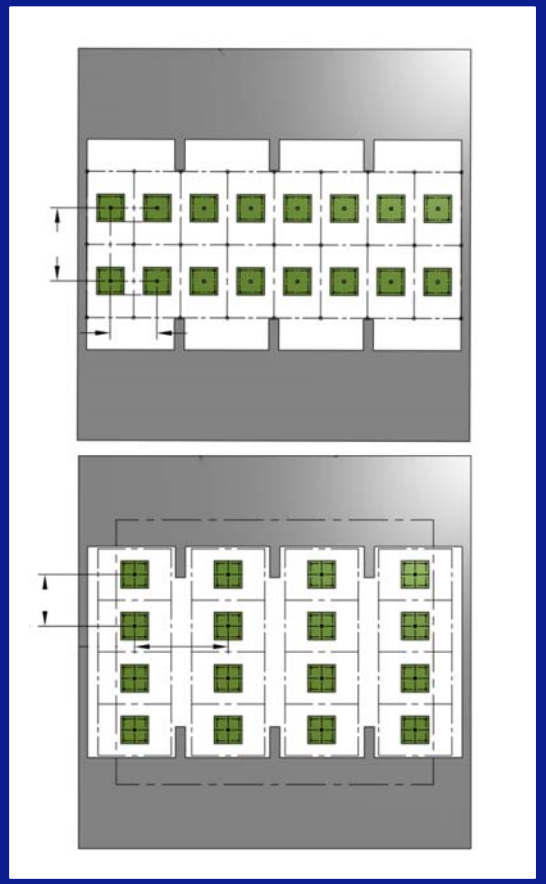
- Baseline RF economics for x8 sites.
  Representative model enables study of lifetime cost of test versus CapEx & OpEx.
- RF plan for x16 sites.
  High-level, compare and quantify site density benefits by TCO.
- Fleet planning assumptions
  - 100M units per year @ 80% utilization
  - 30 secs test duration
  - 5 years depreciation, 10 years lifetime
  - 1B total unit shipments



	1	2	3	4	5	6	7	8	9	10
UFx8-OPEX	$13	$26	$39	$53	$66	$79	$92	$105	$118	$131
UFx8-CAPEX	$7	$13	$20	$26	$33	$36	$39	$42	$45	$48

First-Order Approximation

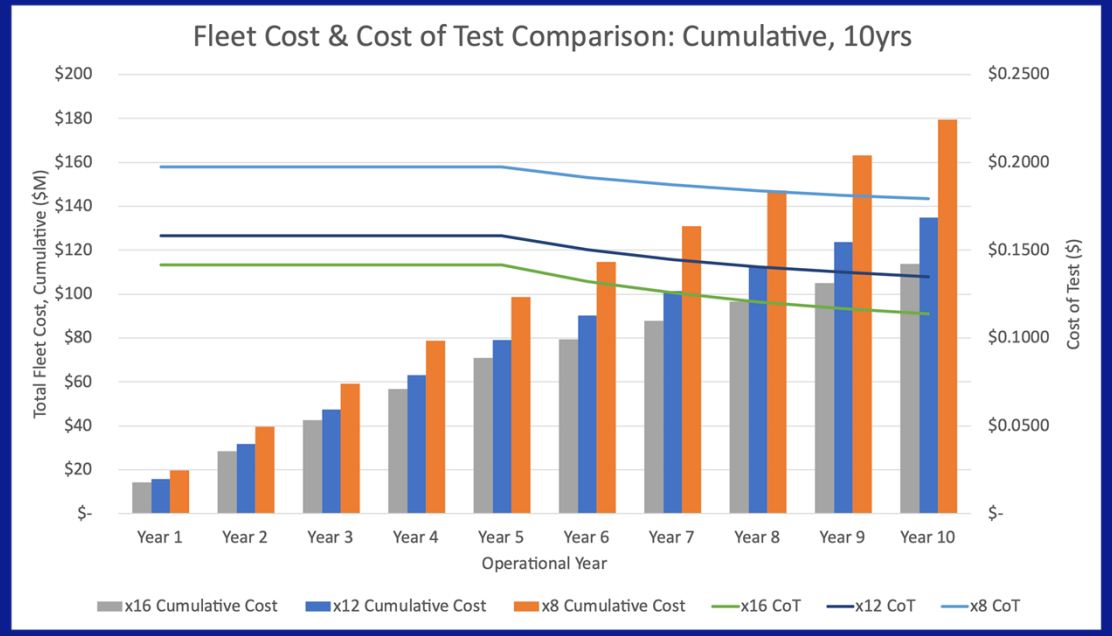
- Factor of test cells in fleet
- OpEx: Operational cost/hr as function of floor space
  - And consumables
- CapEx, total test cell
  - ASP tester
  - ASP handler (< 2x expensive for x16)
  - DUT board, 1-yr depreciation
- Cost of Test per DUT: $(CapEx_{depr} + OpEx) / units$
- Total cost of ownership, TCO



Total Lifetime Overview: x8, x12, x16 sites

Results & Discussion

- Cumulative CoT (& TCO) results
  - X8 → $0.18 ($180M)
  - X12 → $0.13 ($140M), 25%
  - X16 → $0.11 ($115M), 35%
- Year 1
  - CapEx & OpEx set cost trajectories
- Years 5-10
  - Note >10% effect after depreciation
  - X16 has 20% improvement

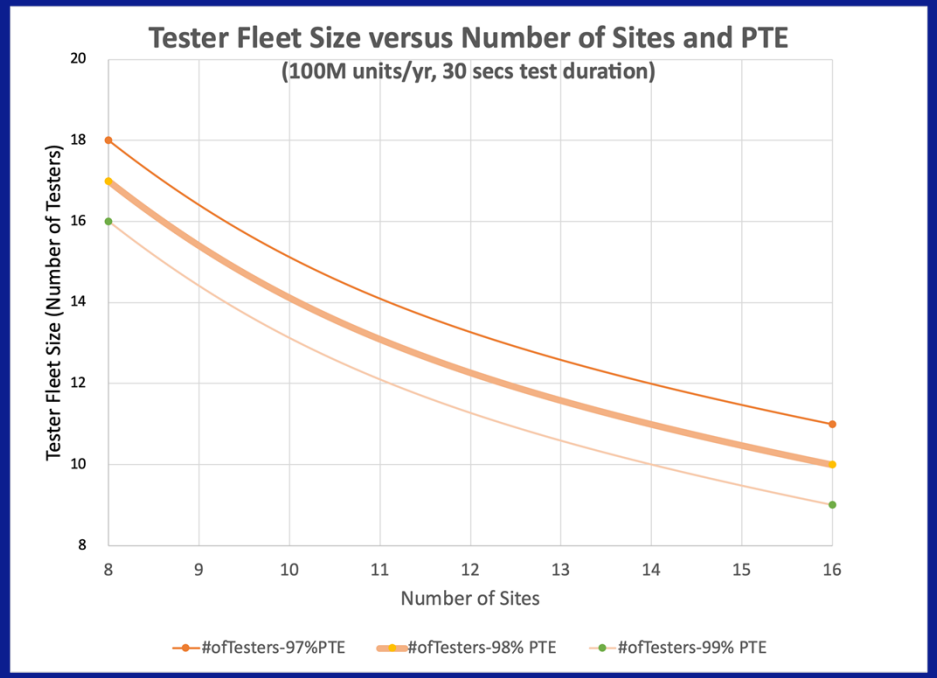


TestConX™

Fleet Size versus Site Density

Results & Discussion

- Double the site density equates to half the fleet size.
- OpEx impact is dramatic.
- Parallel Test Efficiency (PTE) matters; in fact, 1% PTE delta at x16 sites affects fleet size by 10%.
- Additional PTE versus Site Count on CoT insights available[1]



	#ofTesters		
#ofSites	97% PTE	98% PTE	99% PTE
x8	18	17	16
x16	11	10	9

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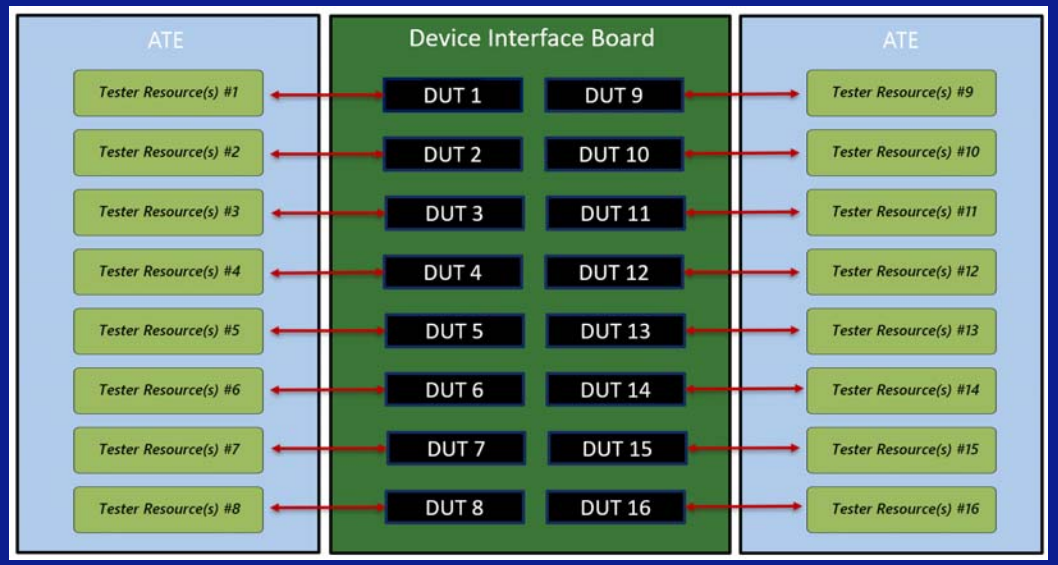
[1] R. Kramer, "Test strategy implications on cost of test," Electronic Design, Jan. 25, 2018.

Parallel Test Efficiency (PTE) Refresher

Results & Discussion

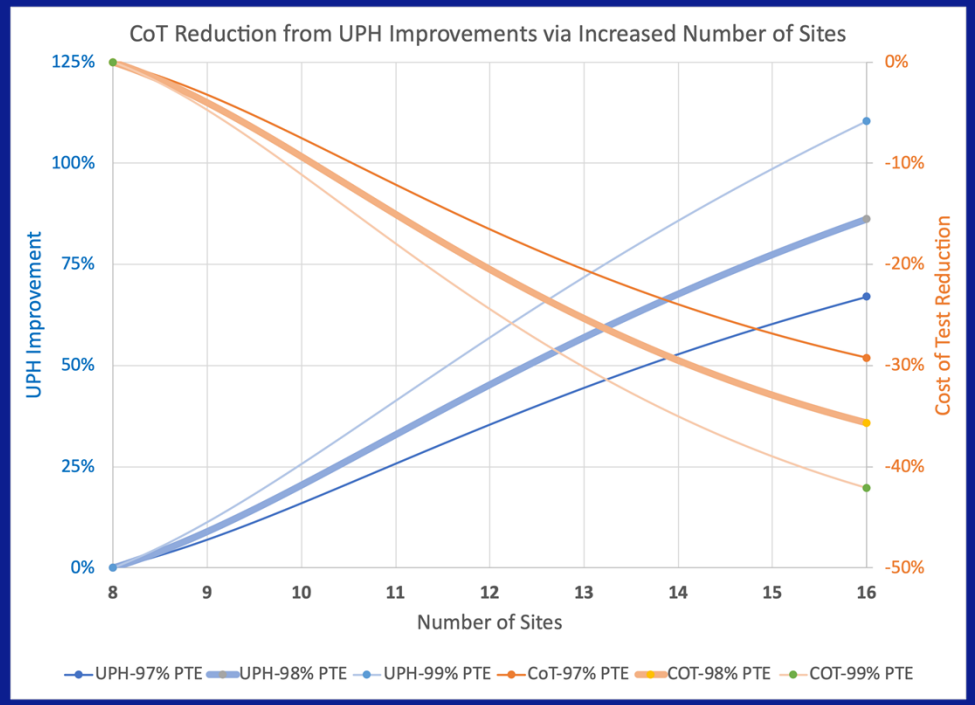
- Ideally, 100% PTE equates to truly parallel operation.
- Practically, PTE degrades as some operations become serialized.
- Test engineers optimize their test plans for quality control and highest possible PTE, otherwise test duration degrades proportional to serial impacts.
- Tester complexity that we cannot afford to ignore.



Fleet Size versus Site Density

Results & Discussion

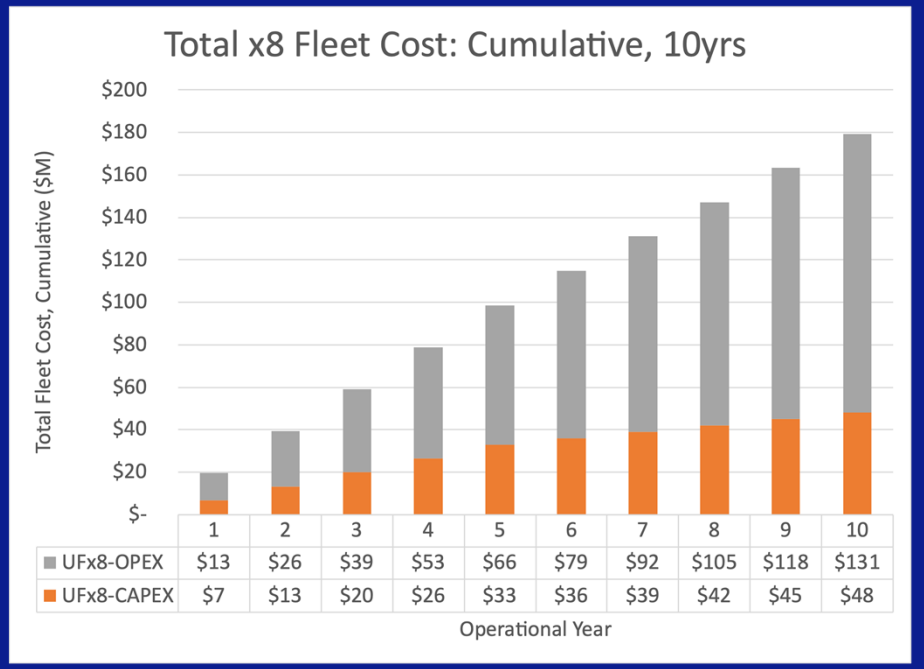
- Double the site density equates to higher units per hour (UPH), depending on PTE.
- 1% PTE delta at x16 sites equates to 20% UPH improvement.
- At higher site density, CoT fluctuates depending on PTE.



Breakdown Capex & OpEx: x8 Sites

Results & Discussion

TCO cumulative lifetime costs are dominated by OpEx (not CapEx).



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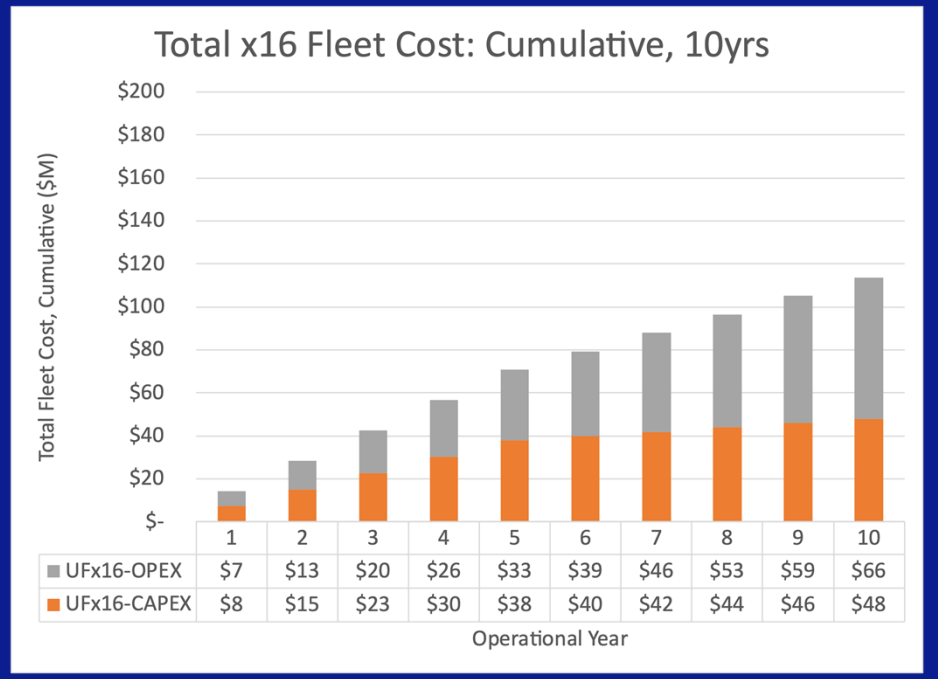
Breakdown Capex & OpEx: x16 Sites

Results & Discussion

TCO cumulative lifetime costs are now more evenly distributed (and lower overall).

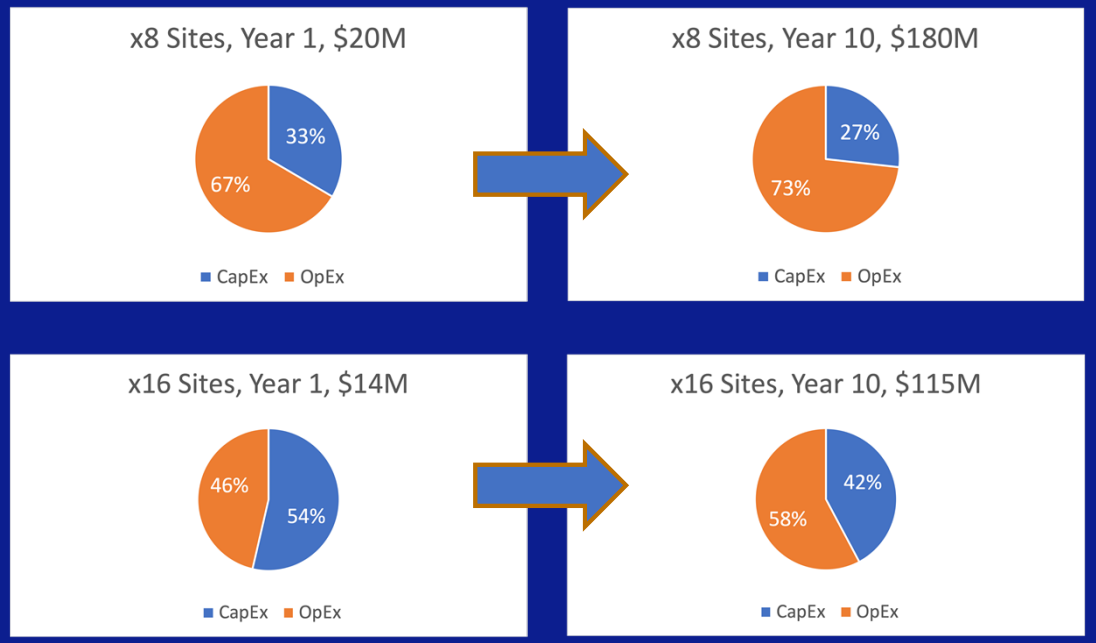


	1	2	3	4	5	6	7	8	9	10
UFx16-OPEX	$7	$13	$20	$26	$33	$39	$46	$53	$59	$66
UFx16-CAPEX	$8	$15	$23	$30	$38	$40	$42	$44	$46	$48

Lifetime Comparison: x8 versus x16 sites

Results & Discussion

- At x16, note redistribution of expenses towards CapEx.
- Higher CapEx that delivers greater UPH is desirable.
- Cuts the fleet size in half leads to dramatically lower OpEx and total CoT.



Conclusion

- As these results demonstrate, parallelism and efficiency are powerful mechanisms fueling relentless cost reductions in the high volume manufacturing semiconductor ecosystem.
- The biggest financial decision is the selection of site density for new silicon.
- 5G complexity & economics will motivate greater site density.
- Double the site density cuts the fleet size in half and greatly reduces TCO.
- PTE optimizes CoT results, especially at higher site counts.

Recommendation

We should all continue to prioritize our total CoT activities in the following order:

1. Minimize OpEx with focus on UPH, including optimal PTE
2. Minimize test duration for optimal yield, including defect escapes
3. Minimize CapEx

Future Work

- Transceiver trends: convergence FR1-FR2 (5G-IF)
- Antenna to Bits, beamforming trends: Over The Air (OTA) methods (FR2-mmWave),
- DIB complexity topics: application space size, signal delivery, signal integrity, co-location, interference, site-to-site correlation
- RF to Bits, interface trends for RF, mmWave, OTA and for high speed serial
- Signal delivery technology, including data for blind mate interface versus insertion count
- Test methodology: RF calibration repeatability & stability

References

PTE versus site count

[1] R. Kramer, "Test strategy implications on cost of test," Electronic Design, Jan. 25, 2018.

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